Improved Cooling Design for High Power Waveguide System

W. C. J. Chen and R. Hartop
Radio Frequency and Microwave Subsystems Section

An improved cooling method in waveguide system was designed for high power test. Experimental results indicated that this improved design can increase high power handling capability.

I. Introduction

An improved cooling technique has been developed for high power waveguide systems. Testing of X-band high power components in a traveling wave resonator has shown that this improved cooling design reduces temperature in the waveguide and flange. The waveguide power handling capability and power transmission reliability have therefore been increased substantially.

II. Description of Problem

High power transmission capability has been a challenging problem affecting the 400 kW CW X-band radar feed cone at DSS 14. It is well known that breakdown of RF energy often occurs in waveguide systems when power increases to certain levels. There are many factors contributing to the breakdown, e.g., impurities in the waveguide, dimensional mismatching, inadequate cooling, etc.

In the past, several experiments have been conducted to investigate the susceptibility of waveguide to the arc phenomenon during Deep Space Network (DSN) station high power transmission. For example, Yen (Refs. 1, 2, 3) made efforts to study the high power waveguide arcing by using models. Kolbly (Ref. 4) developed an X-band traveling wave resonator (Ref. 5) for high power simulation. In Kolbly's work, heat dissipation in the waveguide was considered to be the major problem in operating the traveling wave resonator, and limited its stable operation to 300 kW CW. Hartop and Bathker (Ref. 6) also pointed out that a major problem in high power X-band planetary radar work was excess heating of waveguide components.

In present high power CW waveguide systems, the waveguide is provided with coolant flowing through ducts soldered on both broad walls of the waveguide. However, it is difficult to apply coolant to the flange area and still provide for easy assembly/disassembly and maintain standard bolt hole patterns. Figure 1 diagrams the common technique of interconnecting WG sections with flexible tubes.

When the waveguide is filled with a dielectric gas, breakdown occurs at a higher power level. Electric strength of dielectric gas at radio frequencies has been researched thoroughly by various authorities (Refs. 7, 8, 9). This research concludes that resistance to breakdown depends mainly on the capability of the gas to absorb free electrons generated by the applied electric field, and then convert the free electrons to heavy negative ions. Under the influence of the increased thermal energy produced from RF insertion loss in the waveguide, the dielectric gas exhibits a thermal effect that speeds up the ionization process, lowers the corona onset, and considerably lowers the gas breakdown potential.

III. Improved Waveguide Cooling Technique

To reduce localized heating (i.e., temperature discontinuities in the waveguide) thereby reducing the single electron avalanche probabilities in the dielectric gas, a new cooling method* for the waveguide system has been designed as diagrammed in Fig. 2. In this improved design, the coolant flows through holes into the waveguide flanges with suitable O-rings designed to prevent coolant leakage at the flange mating surface. A small pressure relief groove is provided between the O-ring and the waveguide to insure that no coolant can leak into the waveguide even in the event of O-ring failure.

IV. Experiment

The JPL-CPR type flange for WR-125 waveguide was modified according to the improved cooling concept. For the purpose of high power testing, the X-band traveling wave resonator was rebuilt with the modified flanges and cooling ducts. Thermocouples were installed on the traveling wave resonator to measure the temperature variation at different power levels, flow rate and types of gas.

A 20-kW CW klystron was used to drive the X-band traveling wave resonator. Before actual field testing, the modified flange design was measured for RF performance. No increased RF leakage through the flange mating surfaces due to the modified design was measured. The level was less than the capability of the instrumentation used for the measurement. The capability of measurement was -90 dB.

*Patent applied for, NASA NPO-15401.

V. Results

Water coolant flow rates of 5.67, 7.57, 9.46, 11.35, and 12.11 liters per minute (1.5, 2, 2.5, 3 and 3.2 gpm) were used during the operation of the high power traveling wave resonator. Nitrogen and sulfur hexafluoride were tested separately and at different flow rates. Test results showing stable, 600-kW power levels were obtained in the X-band traveling wave resonator by using this improved cooling design. The maximum power level was limited only by the 20-kW source. It is expected that higher resonant power would be achieved if the input power could be increased. The temperature in the flanges was 53.3°C (128°F) at 600-kW of power with 2-gpm flow rate. Temperature variations on the waveguide at 7.57 lpm (2-gpm) flow rate are reported here since this flow rate is common at the DSN stations. Flange temperature as a function of resonant power is shown in Figs. 3(a), 3(b).

No arcing was observed during high power testing when either nitrogen or sulfur hexafluoride was used in the waveguide.

Acknowledgement

M. Britcliffe at the Microwave Test Facility at Goldstone provided valuable assistance in operating the traveling wave resonator.

References

1. Yen, H. C., "A Preliminary Model for High-Power Waveguide Arcing and Arc Protection," *The DSN Progress Report 42-48*, pp. 118-125, Jet Propulsion Laboratory, Pasadena, California, December 15, 1978.

2. Yen, H. C., "A Circuit Model for Electromagnetic Properties of Waveguide Arcs," *The DSN Progress Report 42-51*, pp. 193-195, Jet Propulsion Laboratory, Pasadena, California, June 15, 1979.

3. Yen, H. C., "Waveguide Arc Study," *The DSN Progress Report 42-51*, pp. 196-199, Jet Propulsion Laboratory, Pasadena, California, June 15, 1979.

4. Kolbly, R. B., "X-Band Traveling Wave Resonator (TWR)," TR 32-1526, pp. 134-136, Jet Propulsion Laboratory, Pasadena, California, October 1973.

5. Miller, S. J., "The Traveling-Wave Resonator and High-Power Microwave Testing," *Microwave Journal,* pp. 50-58, September 1960.

6. Hartop, R., and Bathker, D. A., "The High-Power X-Band Planetary Radar at Goldstone: Design, Development, and Early Results," *IEEE Transactions On Microwave Theory and Techniques*, Vol. MTT-24, No. 12, pp. 958-963, December 1976.

7. Gibson, J. W., and Miller, C. F., "The Electric Strength of Sulfur Hexafluoride at Radio Frequencies," *Journal of Electrochemical Society*, Vol. 100, No. 6, pp. 265-271, June 1953.

8. Morris, J. C., Krey, R. U., and Bach, G. R., "The Continuum Radiation of Oxygen and Nitrogen for Use in Plasma Temperature Determination," *J. Quant. Spectrasc. Radiat. Transfer*, Vol. 6, pp. 727-740.

9. Brown, S. C., "High Frequency Gas Discharge Breakdown," *Handbuch der Physik.* XXII, 1955.

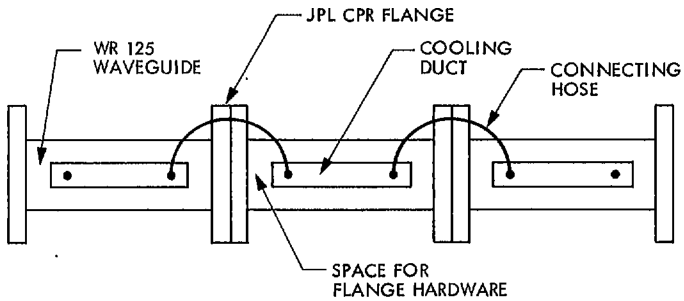

Fig. 1. Original cooling design of waveguide system

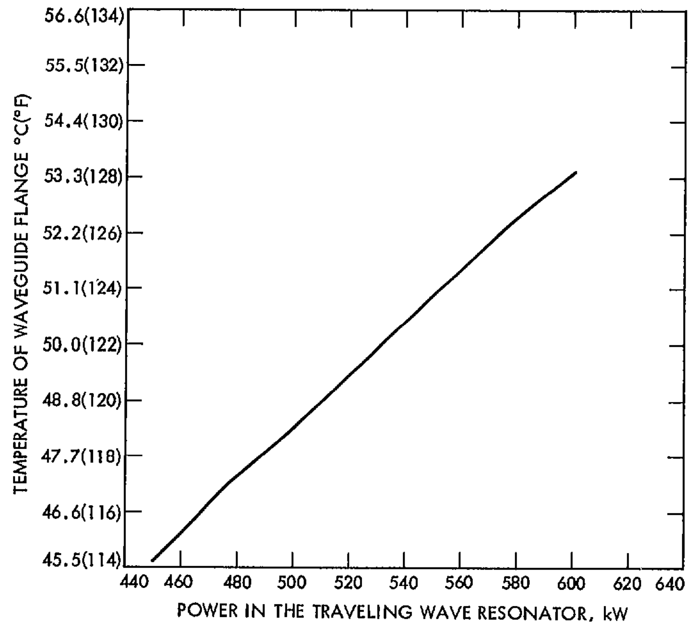

Fig. 3(a). Temperature variation of flange as a function of resonant power. Flow rate 7.57 lpm (2 gpm), nitrogen dielectric gas, modified cooling design. The spot temperature of flange exceeded 148.8°C (300°F) with 300 kW power limitation in the original cooling design

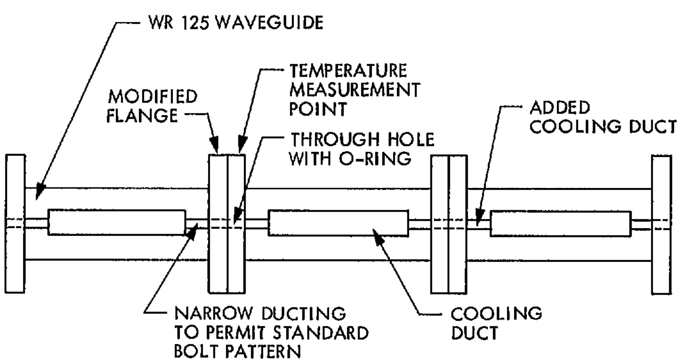

Fig. 2. Modified cooling design of high power waveguide system

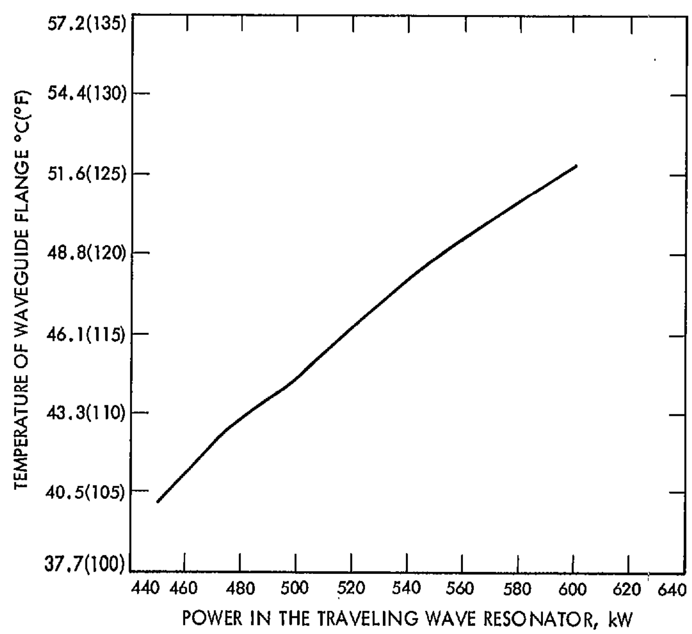

Fig. 3(b). Temperature variation of flange as a function of resonant power. Flow rate 7.57 lpm (2 gpm), sulfur hexaflouride dielectric gas, modified cooling design